CROP PRODUCTION RESPONSE TO MOISTURE SUPPLY IN MINNESOTA

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SPECIAL REPORT NO. 9

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ABSTRACT

The purpose of this report is to define how variations in moisture affect state-wide crop production. To accomplish this goal we controlled geographic variations in the response of crops to changing technology, and regional differences in the severity and timing of wet and dry periods. The regional differences in the moisture supply and crop response are treated by examining them as deviations from local norms or expected values. Technology changes are controlled by subtracting the general trend in yield from the actual yield history.

Yields of major grains are used here with the summer Palmer Drought Index record to examine the role of atmospheric moisture supply on state-wide grain production. The contribution of the northeast to the total state production of grain is so small that we excluded this region from the aggregate state totals.

For oats, wet years are more damaging to total production than drought in the east and both wet and dry years result in slightly reduced production in the southwest. Corn production is slightly poorer during wet years in the east and north, and slightly reduced by both extremely wet and extremely dry years in most other areas of the state. Only in west central Minnesota does soybean production show a weak tendency to be limited by drought events. In other regions the soybean response to moisture is very poorly defined or not statistically significant.

Several factors limit the interpretations of these results. These include: 1) the statistical significance of the relationship between the Palmer Drought Index and the yields, which is not always present in Minnesota; 2) the assumptions of resource homogeneity within the regions, which is a known fact; 3) the fact that these results are not intended as a forecast tool, because they are limited to the time period and place of the derivation.

Pronounced relationships between moisture supply and yield are lacking for a number of crops and regions, with factors other than moisture emerging as prominent in the total state grain production. The large area averaging effect and the variability caused by other factors combine to be so great that drought responses do not appear to overwhelm state aggregate production much more than one year in ten. One should, however, expect local production to be much more responsive to drought than the entire state which is influenced by large-area averaging.

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INTRODUCTION

The purpose of this report is to define the role of variability in available moisture in crop production for use in simulating its effect on the economy of Minnesota with the SIMLAB model. To accomplish this goal several factors need to be subtracted or controlled. These include spatial variability in moisture response of crops, changing technology, and regional differences in the timing of wet and dry periods. The regional differences in the moisture supply and crop response are treated by examining them as deviations from local norms or expected values.

MOISTURE VARIABILITY

The atmospheric moisture supply is examined here with the Palmer Drought Index which represents drought and wet periods relative to regional normals [Palmer 1965]. Because not all months are relevant to crop production, we have aggregated the moisture variability for the summer months, and the record of Minnesota's 9 subdivisions is shown in Figure 1. there is a need to deal with a single state picture of moisture availability to accommodate the focus of the SIMLAB modeling study on the entire state, under the direction of Dr. Richard Lichty. Thus, we have summed the subdivision summer PDI values for each year. The contribution of the northeast toward the total state production of grain is so small that we have excluded this region from the aggregate state totals.

It is necessary to determine the probability of occurrence of the aggregated state moisture supply, and we have done that by ranking the summed summer PDI values for the 8 major grain crop regions. The ranked PDI values are paired with years to select the years that represent the ordering of moisture availability for the period of crop production record of 1930 to 1983. The exceedence values (the percentage of the time that a moisture value is equaled or exceeded) are calculated for the record (Table 1). The fact that drought years are ordered as aggregate for the state does not guarantee that individual regions will have the same ordering. Individual regions won't have the same year as the 25% or 75% exceedence shown in Table 1.

YIELD VARIABILITY

Crop yield variability has two aspects that need to be treated. The first is the secular variability associated with technology. We have handled the first by fitting a regression line to the historic record of yields with the method used by Enz [1976]. Crop yield and acreage data are taken from Minnesota Agricultural Statistics [Minn. Dept of Ag., Cooperative Crop and Livestock reporting Service, 1931-83]. The results are shown in Figures 2 - 5. Variability is then judged as deviations from this technology expectation curve. For example, in region 1 on Figure 2, a yield of 35 bushels per acre represents both a drought in 1980 and wet conditions in 1940. The second aspect of crop yield variability is regional differences in yields related to the differences in local factors of production and in the lack of spatial autocorrelation (the similarity of adjacent places) in wet

TABLE 1.

MINNESOTA SUMMER DROUGHT EXCEEDENCES

% EXCEEDENCE	YEAR	TOTAL PDI VALUES FOR SUMMER FOR 8 DIVISIONS
2	1944	80
4	1965	65
6	1979	63
7	1953	61
9	1945	59
11	1983	59
13	1962	59
15	1943	52
17	1951	50
19	1957	48
20	1972	45
22	1942	43
24	1978	40
26	1968	35
28	1969	33
30	1982	28
31	1966	26
33	1971	22
35	1952	19
37	1947	18
39	1946	16
41	1981	15
43	1974	13
44	1950	12
46	1960	11
48	1975	10
50	1963	6
52	1954	4
54	1941	4
56	1967	2
57	1973	2
59	1964	-7
61	1938	-9
63	1949	-10
65	1935	-12
67	1970	-17
69	1948	-20
70	1956	-21
72	1958	-22
74	1959	-35
76	1939	-35
78	1937	-36
80	1955	-40
81	1977	-44
83	1930	-45
85	1961	-47
87	1980	-51
89	1940	-63
91	1932	-63
93	1976	-73
94	1936	-75
96	1931	-86
98	1933	-90
100	1934	-163

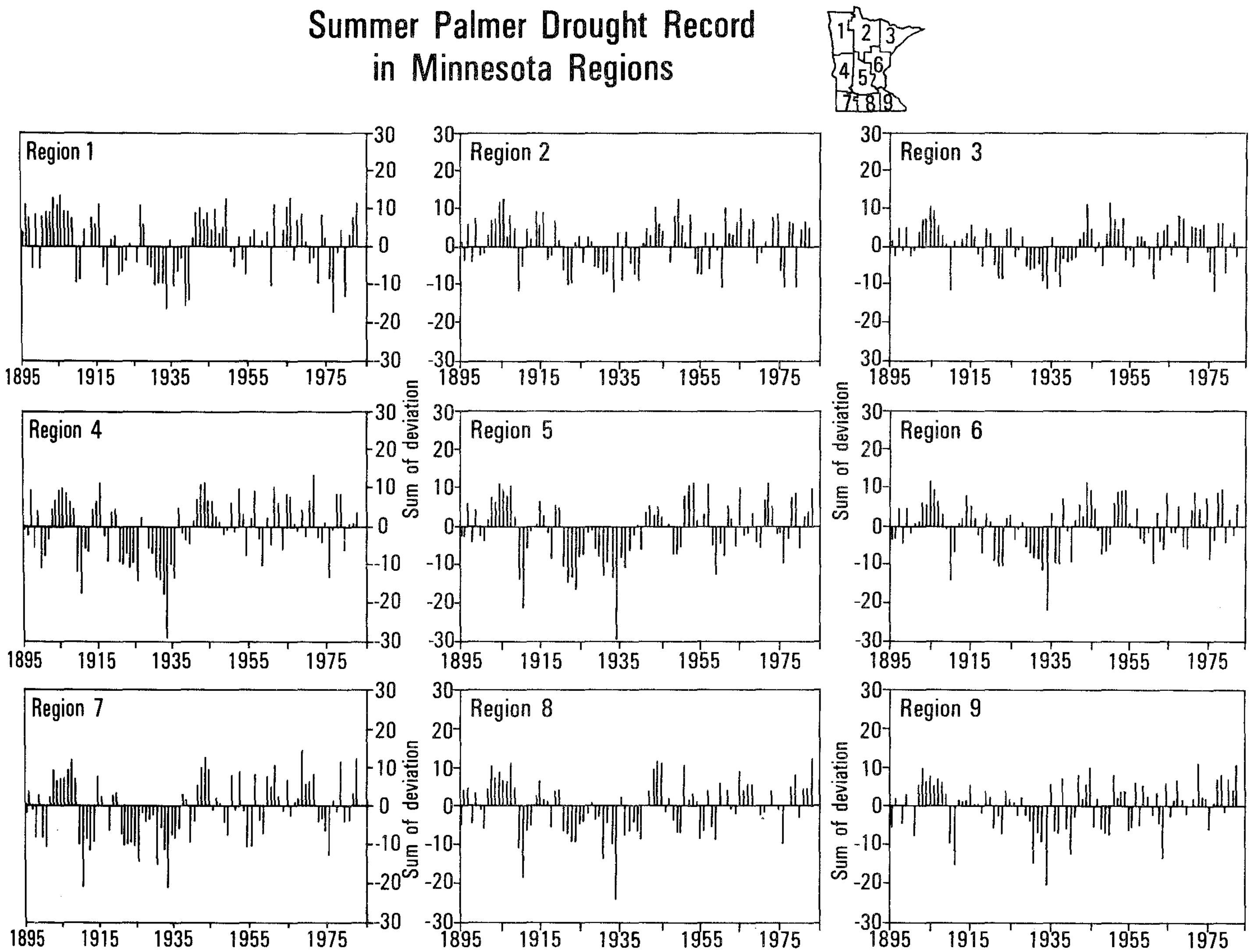

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Figure 1. Values represent the sum of June, July, and August PDI values for the years 1895 to 1983. Negative values represent dryer than normal years and positive values represent years with above normal moisture conditions. The patterns of historic moisture variability are not uniform among the 9 Minnesota climatic subdivisions.

Data from The National Weather Service

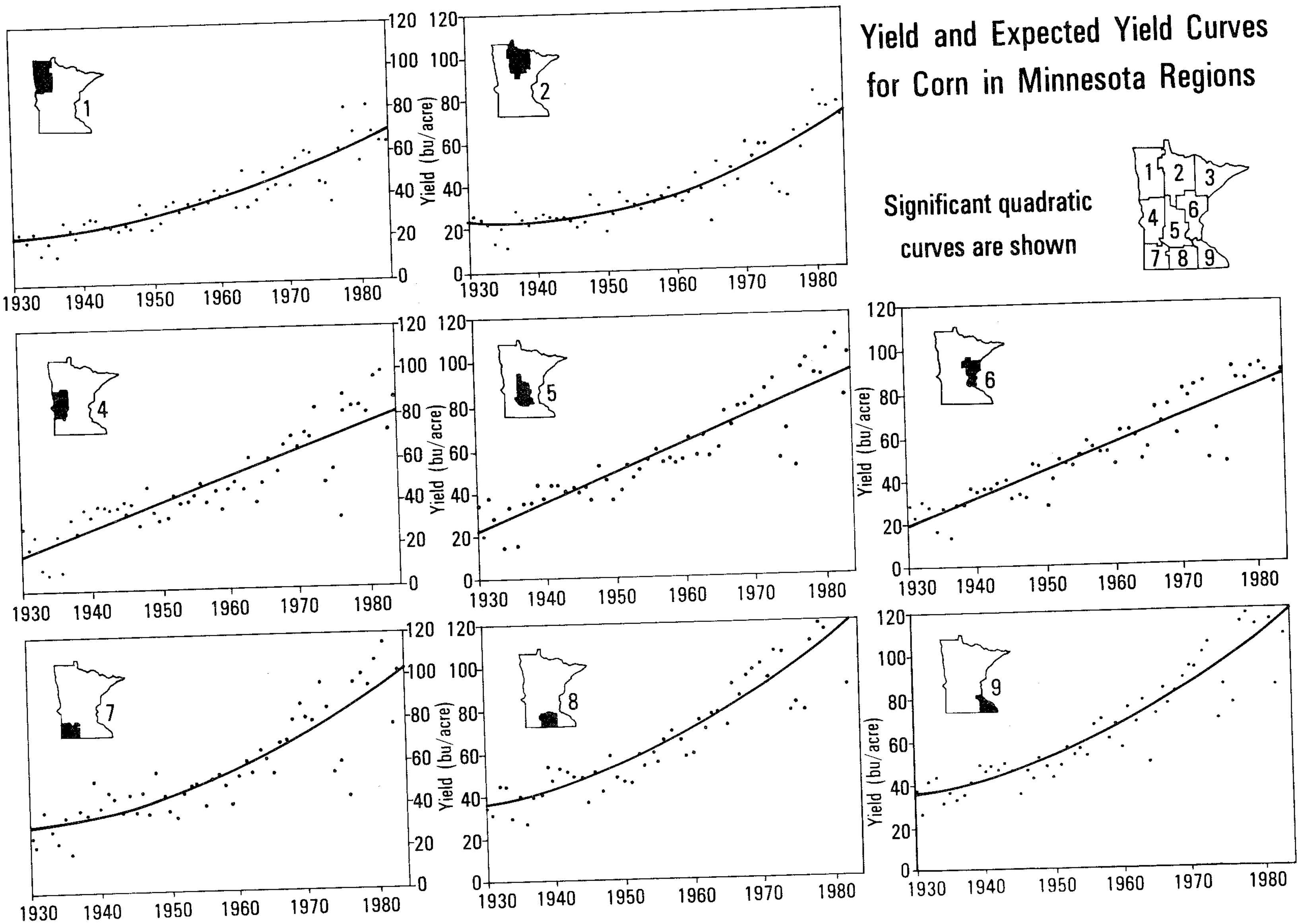

Figure 2. Historic Trend of Corn Yield Records for 8 Minnesota Climatic Subdivisions

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Data from The Minn. Dept of Agriculture

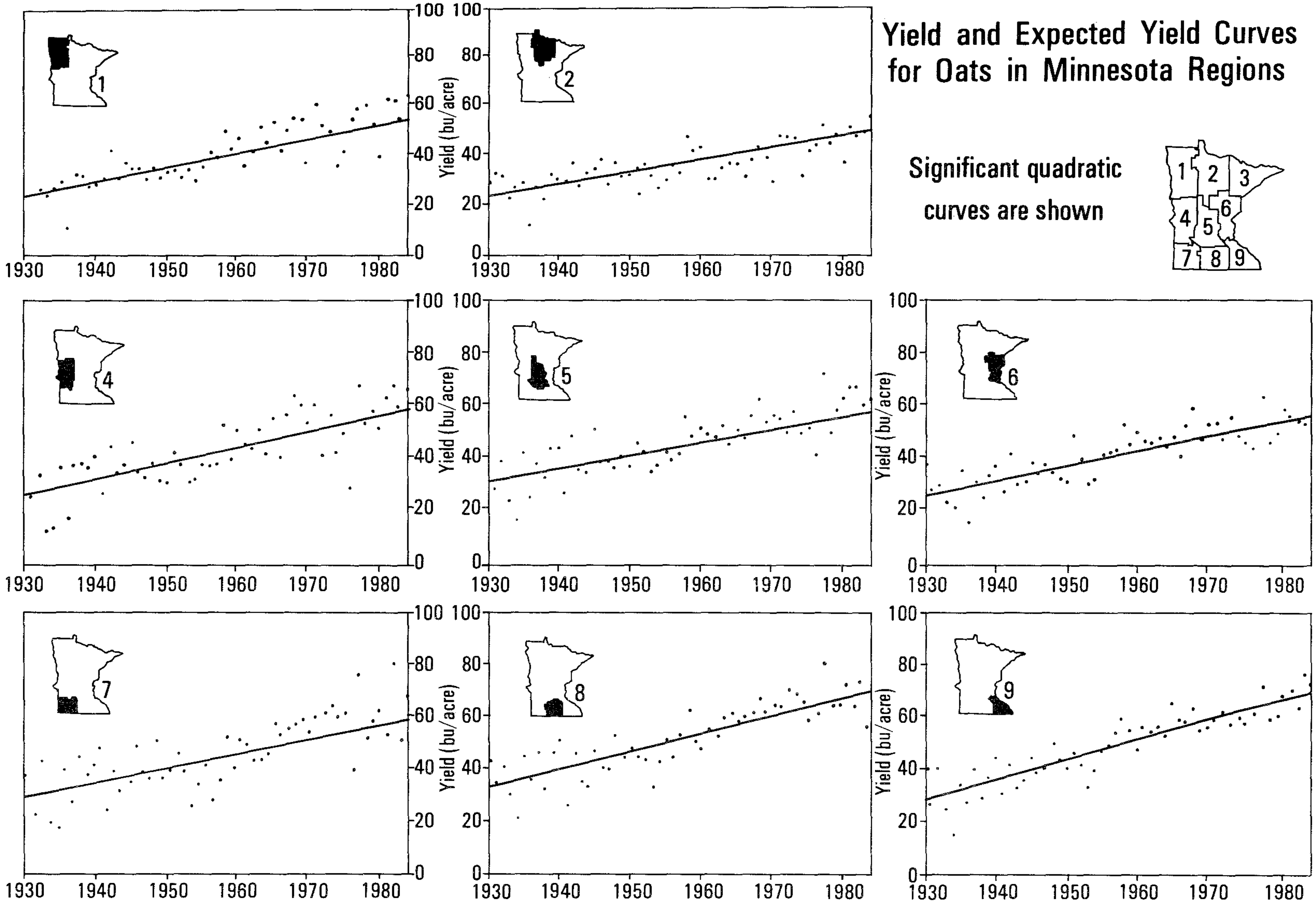

Figure 3. Historic Trend of Oat Yield Records for 8 Minnesota Climatic Subdivisions

Cartography Laboratory, Department of Geography, The University of Minnesota
Data from The Minn. Dept of Agriculture

Cartography Laboratory, Department of Geography, The University of Minnesota
Data from The Minn. Dept of Agriculture

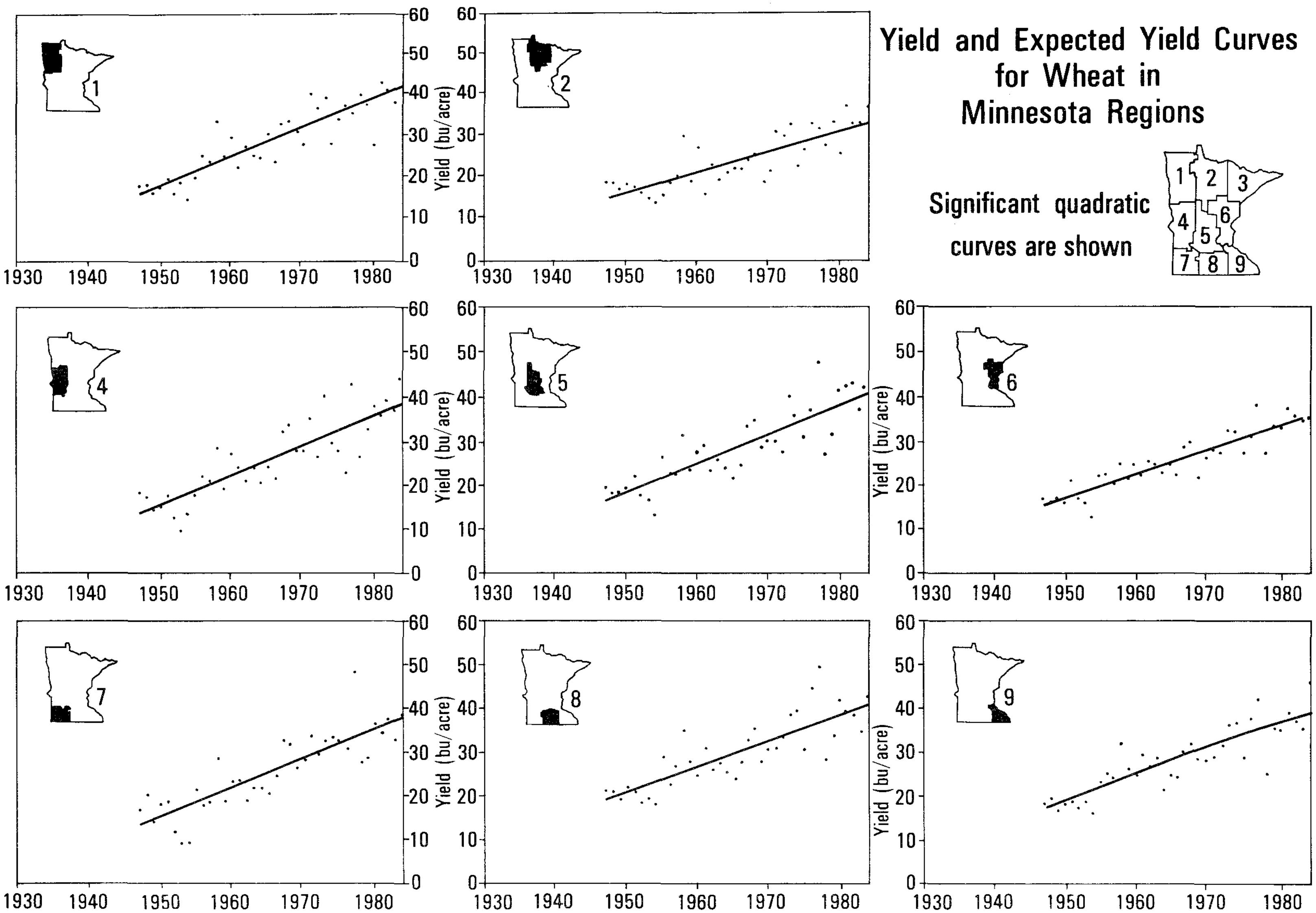

Figure 5. Historic Trend of Wheat Yield Records for 8 Minnesota Climatic Subdivisions

Cartography Laboratory, Department of Geography, The University of Minnesota
Data from The Minn. Dept of Agriculture

and dry periods. The effect of local factors is treated by calculating expected yield for each region and summing the regional production totals for selected years.

The regional differences in the oat, corn, and soybean yield response to moisture variations are shown in Figures 6 - 8. For oats, wetter years are more damaging in the east and the distribution in the southwest is weakly quadratic (Figure 6). Corn shows a slightly poorer yield during wet years in the east and north, with a very weak quadratic tendency in most regions (Figure 7). Only west central Minnesota shows a weak quadratic relationship between percent of expected soybean yields and Palmer Drought Index values (Figure 8).

Several time requirements controlled the design of this study. First, 1982 is given as the base year for comparison. Second, the crop production response to the moisture situation of the state was to be calculated for the 25% (wet, 1978 is the closest year) and 75% (dry, 1959 is the closest year) exceedence years. The 1982 exceedence is 30% (Table 1).

The expected crop yield for a selected exceedence year is corrected to 1982 ($CPEY_{82}$) by converting its yield deviation to percent-of-expected yield (PEY_E) and adding this value to the percent-of-expected for 1982 (PEY_{82}). The $CPEY_{82}$ is multiplied by the actual 1982 yield (Y_{82}) and the 1982 acreage (A_{82}) to get the estimated production for the exceedence year (EB_E). To get the estimated effect of variations in moisture availability for the base year, the calculated difference in production (CBD_E) between a selected exceedence year (EB_E) and 1982 (B_{82}) is added to the 1982 production (B_{82}). These calculations are done in the following manner:

$$CPEY_{82} = PEY_E + PEY_{82}$$

$$EB_E = Y_{82} * CPEY_{82} * A_{82}$$

$$CBD_E = B_{82} + EB_E$$

The calculated difference in production (CBD_E) is shown in bushels in Table 2 for oats, corn, and soybeans.

TABLE 2. Estimated impact of moisture variability on state-wide production of major Minnesota grains for selected moisture exceedence years. The response of corn (C) is fairly strong. Oat (O), and soybean (S) production are more strongly affected by other factors than by their response to summer moisture differences. Production figures are based on Minnesota acreage planted to each crop in 1982 using the technology of 1982. Bushel figures are in millions .

Year	Percent Time Exceeded	Normal Expected (Bushels)			Difference Predicted (Bushels)			Difference Predicted (Percent)		
		C	O	S	C	O	S	C	O	S
1978	24	645	94	135	119	-30	17	18	-32	13
1982	30	645	94	135	0	-2	0	0	-2	0
1963	50	645	94	135	67	-11	-23	10	-12	-17
1959	74	645	94	135	-61	-23	-77	-9	-25	-57
1977	81	645	94	135	104	14	24	16	15	18
1976	93	645	94	135	-209	-56	-178	-32	-60	-131

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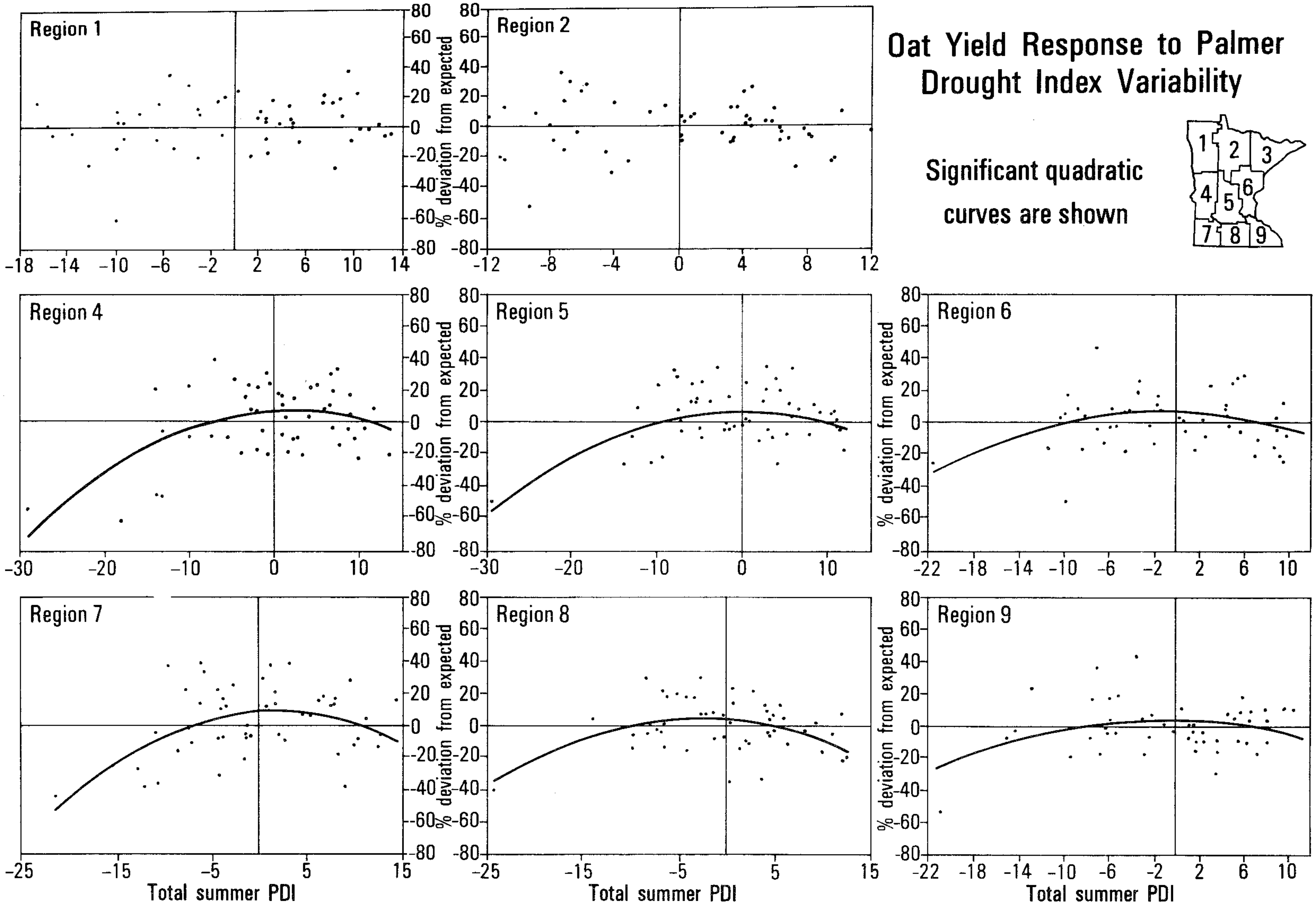

Figure 6. Oat Yield Response to Summer Palmer Drought Index Values for 8 Minnesota Climatic Subdivisions.

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Data from The Minn. Dept of Agriculture and The National Weather Service

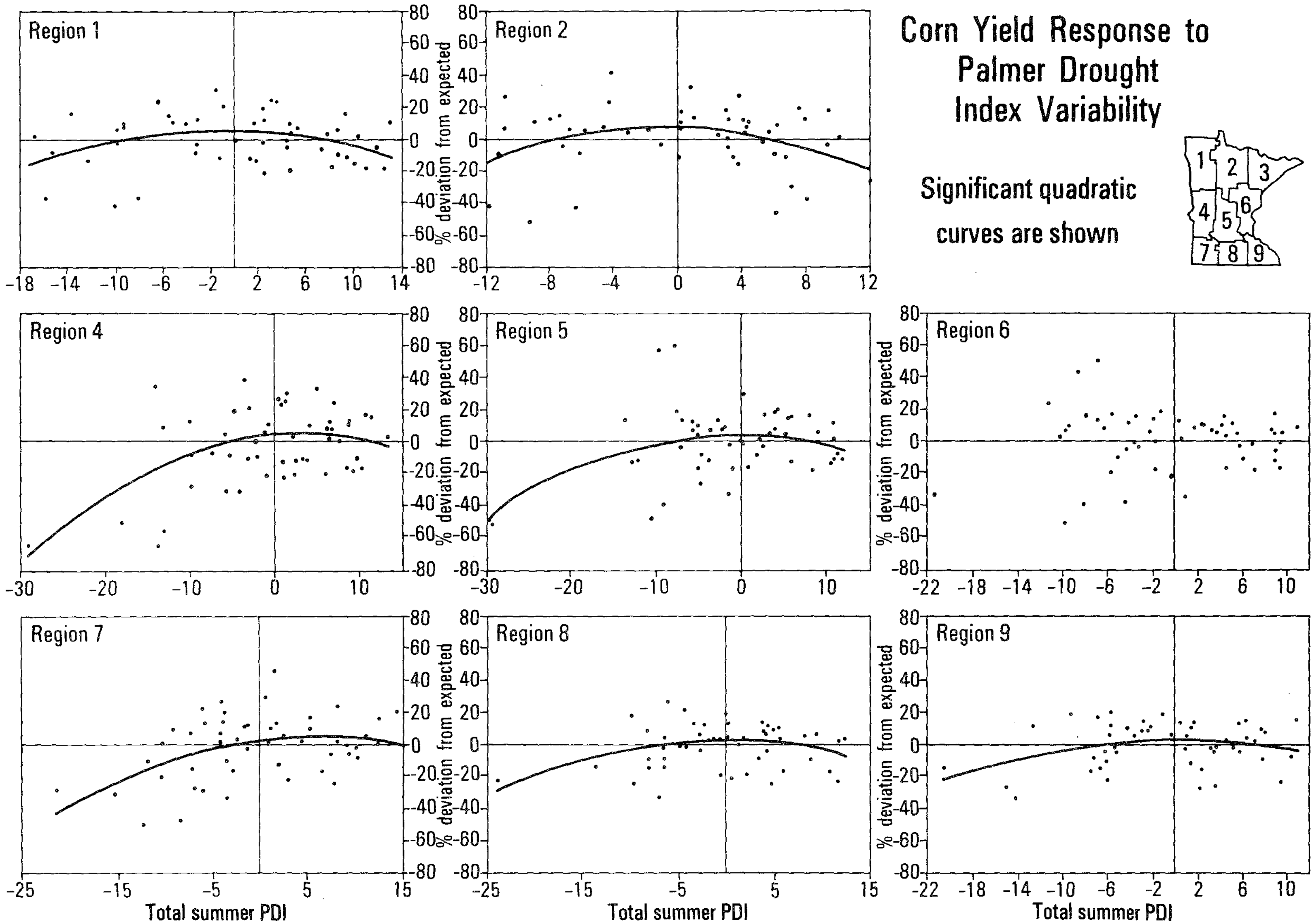

Figure 7. Corn Yield Response to Summer Palmer Drought Index Values for 8 Minnesota Climatic Subdivisions.

Cartography Laboratory, Department of Geography, The University of Minnesota
Data from The Minn. Dept of Agriculture and The National Weather Service

Minnesota Climatic Subdivisions.

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Data from The Minn. Dept of Agriculture and The National Weather Service

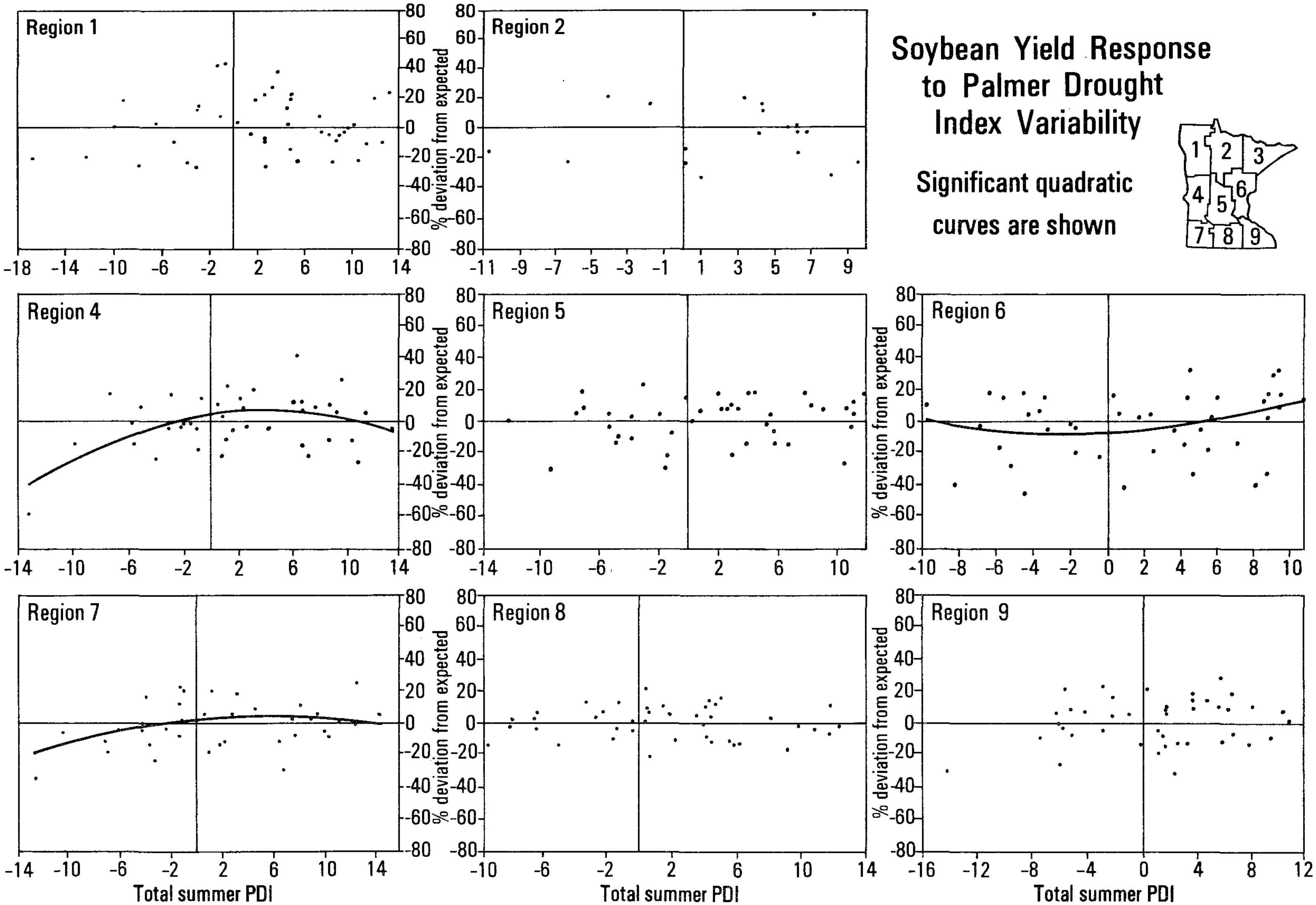

Figure 8. Soybean Yield Response to Summer Palmer Drought Index Values for 8 Minnesota Climatic Subdivisions.

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Data from The Minn. Dept of Agriculture and The National Weather Service

It is obvious that the sequence of expected production ordered by moisture exceedence is better for some crops than others (Table 2). In the case of small grains the results are poorly defined or inconclusive, primarily because of the drought evading character of the crops and the fact that they are not severely moisture limited in the drier areas of Minnesota even during drought years.

LIMITATIONS

Several data and physical factors limit the interpretations of these results. These include the statistical significance of the relationship between the Palmer Drought Index and the yields, the assumptions of resource homogeneity within the regions, and the fact that these results are not intended as a forecast tool. Thus, they are limited to the time period and place of the derivation. As can be seen from some of the XY plots of yield deviations and PDI values, pronounced relationships are lacking for a number of crops and regions. Table 2 suggests that factors other than moisture are prominent in the total state grain production. In fact it seems that the variability caused by other factors is so great that drought responses do not overwhelm state aggregate production above the 90% exceedence level. However, one should expect that local production would be much more responsive to drought because the large-area averaging effect does not apply.

If the technology curve is calculated from non-drought years, the values would be less conservative and drought would not be a factor in the expected yield curve. This would result in an increase in the effect of drought but diminish the effect of wet years. It seems better to us to look at the whole picture, as we have done here, rather than treat drought as a nonnormal condition.

REFERENCES

Enz, John W., 1976, The Influence of Induced Rainfall on Corn and Soybean Yields in Minnesota, Unpublished PhD Dissertation, The University of Minnesota.

Palmer, Wayne, 1965, Meterological Drought, U. S. Weather Bureau, Research Paper No. 45, 58 pp.

Minnesota Dept of Agriculture, Cooperative Crop and Livestock Reporting Service Minnesota Agricultural Statistics 1930 to 1983.